

TABLE 4.—*Maximum specific humidity values*

Station	Time of occurrence	Date	Parts per thousand
Bay Region:			
San Francisco.....	5 a.m.	15	9.75
Oakland Airport.....	Noon	16	11.99
San Francisco Airport.....	9 a.m.	16	11.17
Santa Clara Valley:			
Sunnyvale Naval Air Station.....	Noon	16	12.86
Mount Hamilton.....	1 a.m.	16	12.50
Eastward across the valley:			
Sacramento.....	5 p.m.	15	11.21
Auburn.....	1 p.m.	16	12.17
Blue Canyon.....	1 p.m.	16	16.58
Reno.....	9 a.m.	16	11.38
Northward in valley:			
Williams.....	5 p.m.	15	11.65
Red Bluff.....	5 a.m.	16	10.92
Redding.....	10 a.m.	16	11.47
Southward in valley:			
Atwater.....	1 p.m.	16	13.90
Fresno.....	Noon	16	11.70
Bakersfield.....	9 a.m.	16	12.63
Sandberg.....	1 a.m.	16	13.10

It will be noted that there is little difference in the specific humidity at any of the stations, including Mount Hamilton. This leaves no doubt as to the identity of the air mass involved. Blue Canyon specific humidity appears to be too high, but a thunderstorm occurred there on the 16th and the light rain which fell may have been responsible for the high value.

The weather map of 8 a.m. of the 14th shows that the trough from the southwest low in working northward has severed the oceanic and plateau highs. Conditions in the interior valley were still stagnant and Red Bluff reported the highest August temperature of record, as Sacramento had done the preceding day. Wind movement at all levels in the free air was predominantly westerly by the morning of the 15th, indicating that the transition period was over and that the control had passed from the dry hot air to the humid marine air. The marine air by this time had increased greatly in depth and had become deeper than the altitude of the coastal mountains. The eastward moving mass of cool, moist air passed over the coast range, across the interior valley and over the Sierra Nevada. Its forward edge had all of the characteristics of a cold front. On the 16th thunderstorms occurred

throughout the entire length of the Sierra as indicated by reports from the fire weather stations and airways stations in the mountains. Reno also reported a thunderstorm on this date. Following the passage of the cold front the pressure rose rapidly; and by the evening of the 16th the Pacific high again extended into the plateau, the "land breeze" was again predominant. A few days later it was again superseded by the air from the ocean and the conditions discussed above were repeated, but to a less degree. The inevitable stratus clouds formed in the Bay Region on the night of the 14th-15th. On this date the marine air was much deeper, and the maximum temperature somewhat lower than on the preceding day. The cooling necessary to reach the dew point, which was practically the same as on the previous day, would be much less. Cooling on this night would be most pronounced at the upper surface of the marine air, where radiation is most active. Six hundred feet was the height of the first few patches of cloud that formed at the Oakland Airport about 11 p.m. of the 14th. Ceiling light measurements made some time later gave the height as 700 feet. The ceiling decreased to 300 feet by 3 a.m. of the 15th. At San Francisco airport, on the west side of the bay, the clouds did not form until 5 a.m. of the 15th and their base was 800 feet high.

The inversion in temperature had almost disappeared by the 15th and the layer of marine air extended upward to an unknown height. The junction of the marine air and the dry air which it was displacing was at some height above 10,000 feet, the height of the Sunnyvale aerographic flight, part three, figure 3. At such an altitude and after 3 days of contact, the interface would be less marked than when the marine air first pushed inland. The dew point graph of the aerographic flight referred to above shows that the moisture content of the marine air steadily decreased with ascent. A reduction in water vapor would reduce the effective outgoing radiation at the top of the layer. Hence any clouds that formed would do so slowly and if at the surface of discontinuity or somewhat below, would be so high as to be outside of the category of stratus. A few high clouds were noted at Oakland Airport on this night but no summer stratus.

SOME RESULTS OF SOUNDING-BALLOON OBSERVATIONS DURING THE SECOND INTERNATIONAL POLAR YEAR, AUGUST 1932 TO AUGUST 1933, INCLUSIVE

By J. C. BALLARD

[Weather Bureau, Washington, D.C., March 1934]

Sounding-balloon observations were made in the United States on international days of the first and second orders¹ at Dallas, Tex., Omaha, Nebr., and Ellendale, N.Dak. In June 1933 this work was transferred from Ellendale to Pembina, N.Dak., due to the closing of the former station. Six observations per month, made in two series of three flights each, were made at all three stations. In each case the series was begun about noon and the other two flights made at approximately midnight (12 hours later) and 6 a.m. (18 hours later), respectively, 90th meridian time. The total number of observations was 234—by far the largest number of sounding-balloon observations ever made in this country during a similar period. Eighty-five percent of the meteorographs have been returned.

The distribution of the observations with respect to time and place makes it possible to study various annual and

latitudinal variations which heretofore have been undetermined because of lack of adequate data. The relatively short interval of time between the flights in any series also makes it possible to study individual cases of the variations with time of the conditions attending weather changes.

As a whole, the data acquired during the Polar Year is, no doubt, the most reliable yet obtained in this country, largely because of a better understanding of the behavior of the pressure-recording mechanism. However, the temperatures recorded on the day flights probably are still in error owing to insolation effects. If these errors are large, they obviously render the data useless for studying short-range variations accompanying weather changes. As much of this effect as possible was removed from the present temperature records as follows:

On every day on which flights were available for noon and the following midnight, the temperature change from noon to midnight was found for each standard kilometric

¹ That is, the second Wednesday and Thursday and the fourth Wednesday and Thursday in each month, respectively.

level. The averages of these changes at these levels were then found and plotted against altitude. The same procedure was followed for the midnight and 6 a.m. flights. The results of both cases are shown in figure 1. It is clearly shown that the average temperatures recorded on the day flights are higher than those recorded on the night flights, and that the difference between the recorded day and night temperatures increases rapidly with altitude.

Obviously this difference may be due to an actual difference in temperature or to a systematic error. An actual difference in air temperature of this amount, i.e., such a large diurnal temperature range, is not to be expected. The difference is more probably due to errors in the recorded temperatures, the recorded night temperatures being too low or the day temperatures too high. The predominance of radiation over absorption probably tends to cause the instrument at night to record a temperature below that of the air but this error is believed to be negligible. It is therefore believed that practically all of the observed difference is due to the effect of solar

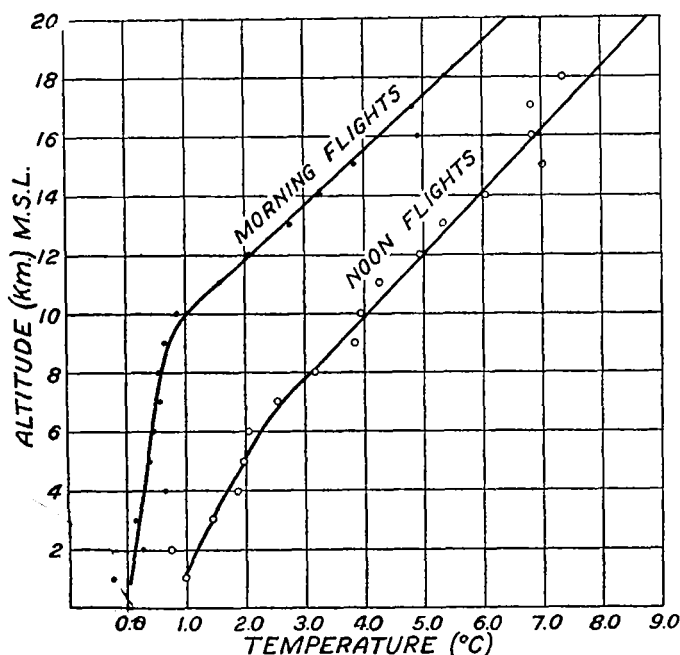


FIGURE 1.—Average errors (caused by insolation) in recorded temperatures plotted against altitude.

insolation. More specifically, it is believed that a large part of the effect is produced by the direct absorption of solar radiation by the temperature element itself, since it is in such a position in the ventilating tube that the sun's rays can strike it both directly and by one or more reflections inside the polished tube when the sun's altitude is great, such as is the case at noon. On the morning flights the sun obviously cannot shine down into the ventilating tube. The errors in the morning temperatures are seen to be smaller at all altitudes than those in the noon temperatures, and are particularly small up to 10 kilometers. Above 10 kilometers, however, the curves have similar slopes, indicating similar causes of the errors in the two cases. It is quite possible that in the early morning flights the sun shines into the tube from the bottom at frequent intervals during the ascent, thus striking the temperature element which is located very near the bottom of the tube.

The increase of the size of the errors with altitude is undoubtedly due to the decrease of air density, and thus of ventilation, with altitude.

Recently, J. Jaumotte (1) has made calculations which appear to prove the impossibility of important insolation effects in the temperatures recorded by his instrument. Obviously, the construction of the Jaumotte meteorograph does not permit solar rays to strike the temperature element directly.

The values obtained from the two curves in figure 1 have been applied to all the recorded temperatures in an effort to obtain values more nearly representative of the actual air temperature than are the observed values. The temperature values were then plotted against altitude and the results are shown in figure 2. The three flights for any series were all plotted on the same axis so the changes of temperature with time at any particular altitude can be observed directly. The curves for the series are so placed that the variation with latitude can also be observed directly.

It will be noted that large temperature inversions in the stratosphere are less frequent than in many other sets of temperature-height curves.

Another characteristic feature of some of these curves should also be mentioned. This is a sort of "false tropopause." That is, the temperature-height curve indicates a normal temperature decrease with height up to about the normal height of the tropopause, and then shows the normal characteristics of a temperature-height curve at the tropopause. Above the tropopause, however the temperature again starts to decrease with height at a rate greater than that ordinarily found in the stratosphere. The most pronounced examples of this occur in the flights of August 24 and 25, at Ellendale; June 7, at Omaha; December 14 and 15, at Ellendale and Omaha; and March 8, at Dallas. This phenomenon might be caused by an unusual amount of convection in the stratosphere or by dynamic effects on a much larger scale, such as subsidence over a relatively large area. However, it appears to be more reasonable to suppose that it is caused either by a current of cold air moving in the stratosphere immediately above the level at which the temperature again commences to fall with increasing height or by the importation of relatively warm air below this level.

Figure 2 furnishes data for every month during the year, which makes it possible for the first time to determine, with a fair degree of accuracy, the annual variation of the height of the tropopause at various latitudes in the United States. Figure 3 shows the height of the tropopause plotted against time of year. The curves drawn through these sets of points are by no means meant to indicate accurately the average heights of the tropopause at the various times and places because this height is so variable that the present number of observations is insufficient to determine it accurately. However, the curves are believed to give a clear and accurate picture of the general tendency and the absolute values are not believed to be greatly in error.

The average height of the tropopause is seen to be greatest in late summer at all three stations and least in late winter. The annual range is relatively small at Dallas, the most southern station, greatest at Omaha, the central station, and small again at Ellendale, the most northern station. The small range at Dallas is to be expected. Here the tropopause is high in summer and its height is decreased only a relatively small amount in winter. At Omaha, the height is expected to vary considerably because of the large annual variation in surface temperature and the overlapping of northern and southern weather conditions. Here the tropopause averages practically as high in summer as it does at Dallas and

nearly as low in winter as it does at Ellendale. At Ellendale, we again have a predominance of one type of weather and, consequently, a smaller annual range in the height of the tropopause.

It is of particular interest to note the points in figure 3, which fall a considerable distance away from the curves, as these points represent unusual conditions. The sig-

amples of the annual variation in pressure at various levels, the surface curve being omitted because of the fewness of observations. The points in this figure which fall far from the curves are likewise of special interest and will be discussed later.

Curves similar to those in figure 4 were drawn for each of the three stations for each standard kilometric level and

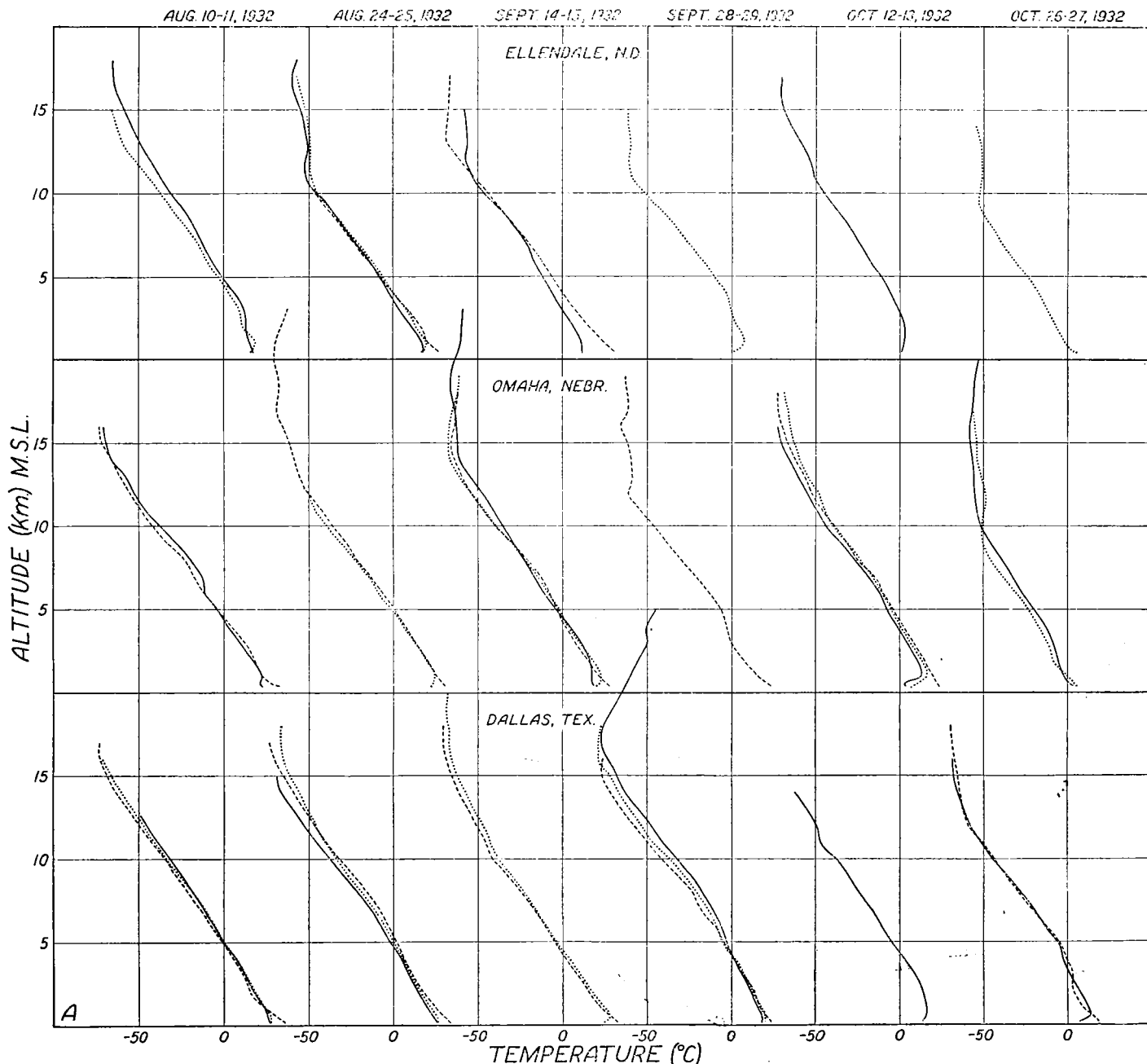


FIGURE 2.—Temperature-height curves; temperatures have been corrected by the amounts indicated in Figure 1 (dashed lines indicate flights made near noon, dotted lines near midnight, and solid lines near 6 a.m.)

nificance of the position of some of these points will be discussed later.

It is well known that the annual variation of barometric pressure is small at the surface and increases with altitude through the first few kilometers. The annual variation of this element up to about 4 km has already been determined for several places in the United States from kite observations (2). The present observations furnish data for much greater elevations. Figure 4 shows some ex-

amples of the annual variation in pressure at various levels, the surface curve being omitted because of the fewness of observations. The points in this figure which fall far from the curves are likewise of special interest and will be discussed later.

Curves similar to those in figure 4 were drawn for each of the three stations for each standard kilometric level and

the annual range indicated by each curve was found. These annual ranges in barometric pressure were then plotted against altitude. The results are shown in figure 5.

It is of particular interest to note that the maximum annual range occurs at about 8 km at all three stations. This altitude is the well-known level of constant density. The maximum annual range is least at Dallas, the most southern station, and greatest at Ellendale, the most northern station. The maximum pressure at all altitudes

higher than about 1.5 km occurs during late summer (August) at all three stations and the minimum pressure occurs about February. During summer, the pressures in these levels average about 2 mb less at Omaha than at Ellendale and about 4 mb lower at Ellendale than at Omaha. However, in winter the pressures at the intermediate levels, i.e., about 4 to 10 km, average about 17 mb lower at Omaha than at corresponding altitudes at Dallas and about 10 mb lower at Ellendale

Figure 6 shows some examples of the type of curve obtained by plotting temperature against time of year for a level in the stratosphere. It is quite evident from these curves that there is a decided tendency for lower temperatures in late summer in the stratosphere than in any other season. The warmest period appears to be late winter or early spring. The most pronounced annual range of temperature is at Omaha and the least pronounced at Dallas. Curves drawn for other levels in the stratosphere

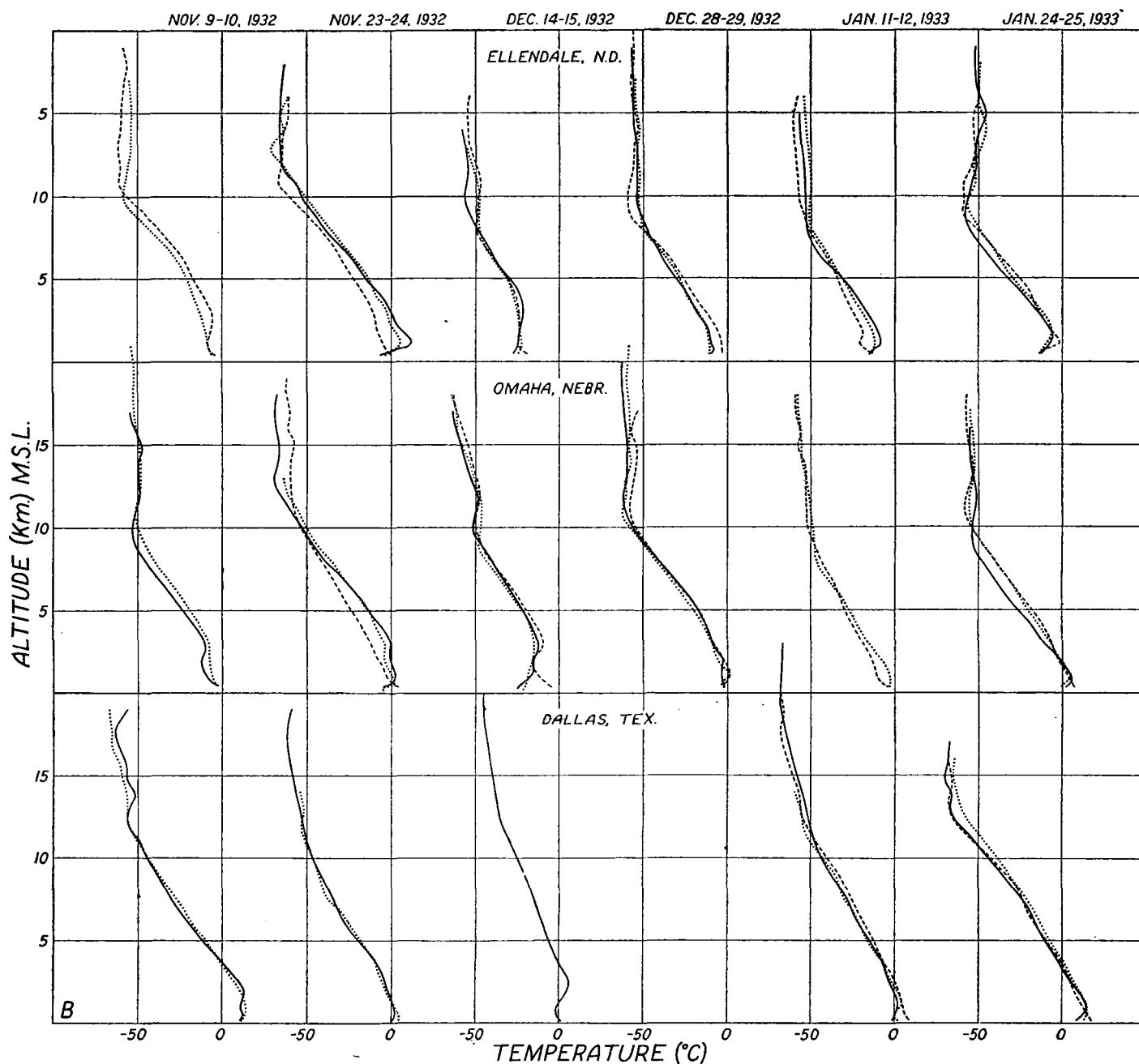


FIGURE 2.—(Continued.)

than at Omaha. At higher levels in winter the latitudinal variation in pressure, i.e., the N-S pressure gradient, decreases rapidly with altitude until at 17 km the average pressure at Omaha is only about 5 mb less than that at Dallas and nearly equal to the average pressure at that altitude at Ellendale.

It is of interest to compare the data just outlined with the averages found by various workers (3) for European stations.

show this tendency even more clearly. The number of observations is insufficient to permit the calculation of reliable means, but it can be said that the annual temperature range at all three stations at altitudes of 15 km and somewhat higher, certainly appears to be of the order of 10° C. This is a striking contrast to the results found for European stations slightly farther north than Ellendale. At these stations the temperatures in the stratosphere are of the order of 5° C. *higher in summer than in winter.*

A. Wagner (4) gives some data for Toronto which are very similar to those obtained in the present series of observations. The averages given by Wagner for the United States stations, on the other hand, show the lowest temperatures to occur in autumn and the highest in summer. These temperatures are probably considerably affected by insolation, seasonal grouping, etc., and should be taken with reservations. It is true, of course,

tally the southward movement en masse of polar conditions in winter.

With regard to temperatures in the stratosphere and height of the tropopause during the passage of high- and low-pressure areas, it may be stated that the present data show tendencies directly opposite to various averages found for the European stations. That is, in a strong high-pressure area in winter, the tropopause is abnormally

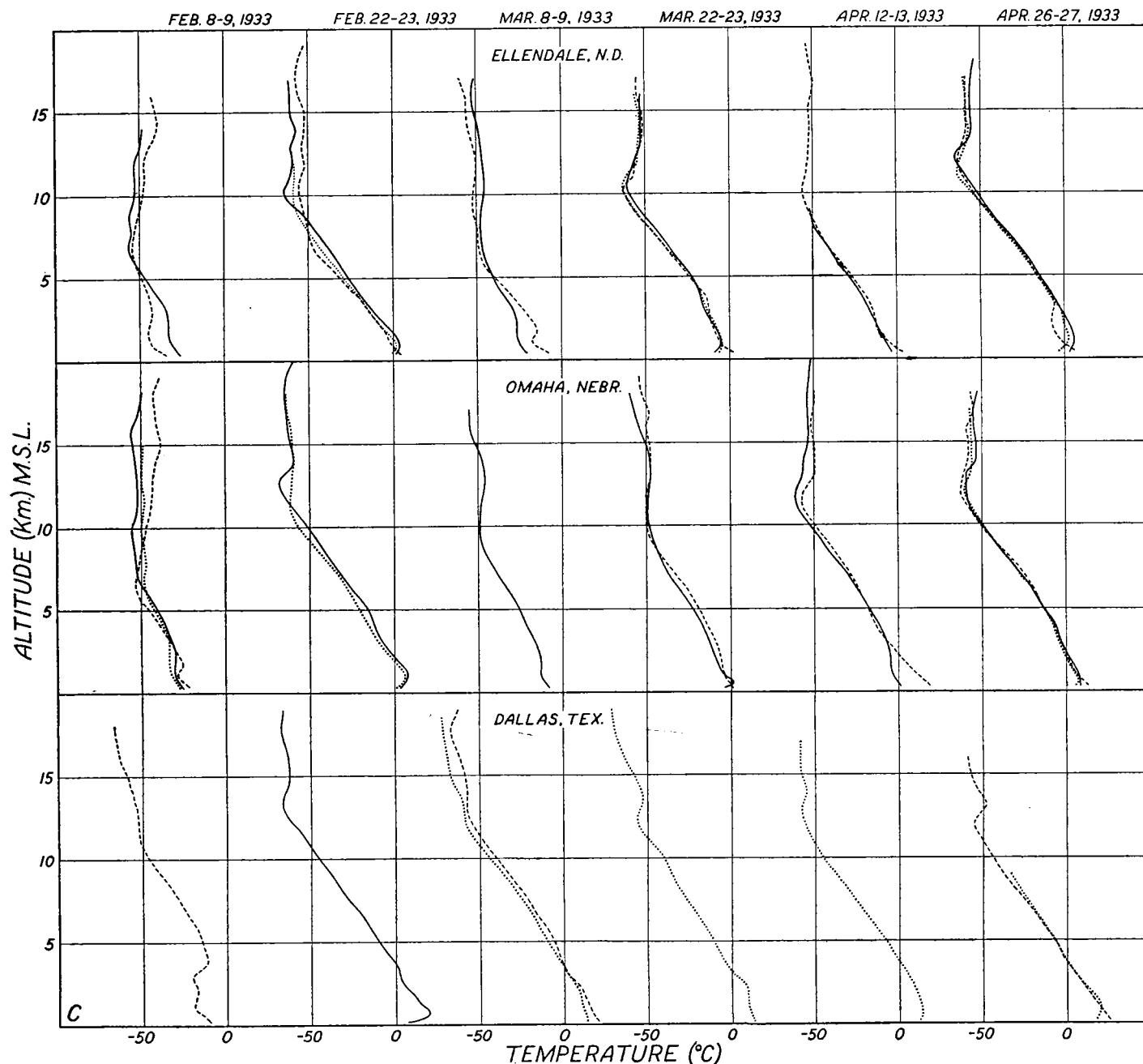


FIGURE 2.—(Continued.)

that the present data were all gathered in a single year which, possibly, was an abnormal year, but it seems probable that they at least indicate the normal trend. It is obvious that curves such as figure 6 give a better indication of the annual trend than a grouping of the values into seasonal normals in which the maximum and minimum points are considerably smoothed.

The cause of this inverse seasonal temperature trend, while undoubtedly complicated, appears to be fundamen-

low and the temperatures in the stratosphere abnormally high. The best examples of this are found in the observations on October 26 and 27 at Omaha and Ellendale, on February 8 and 9 at all three stations, and on March 8 and 9 at Ellendale. Figure 3 shows the tropopause in each of these cases to be 2 to 4 km lower than normal. Figure 4 shows the pressures to be low at all altitudes from 2 km up to 12 to 15 km, and figure 6 shows the temperatures to be high except in the case of March 8 and 9, at Ellendale.

The temperatures in the upper levels at Ellendale and Omaha at noon on February 8 are especially worthy of note since they are approximately equal at the two stations and are the highest recorded during the year at these levels.

The observations on March 8 and 9 at Ellendale are also noteworthy. From noon of the 8th until the following morning the pressure rose at the surface, fell from 2

The temperature on this date rose between noon and the following morning at all levels up to about 5 km and fell at all heights above this.

Such temperature changes at high levels are often explained as being caused mainly by adiabatic expansion or compression. Thus it might be said that on February 8 and 9 the air in the levels nearest the ground is heated in some way, that it then expands and forces the

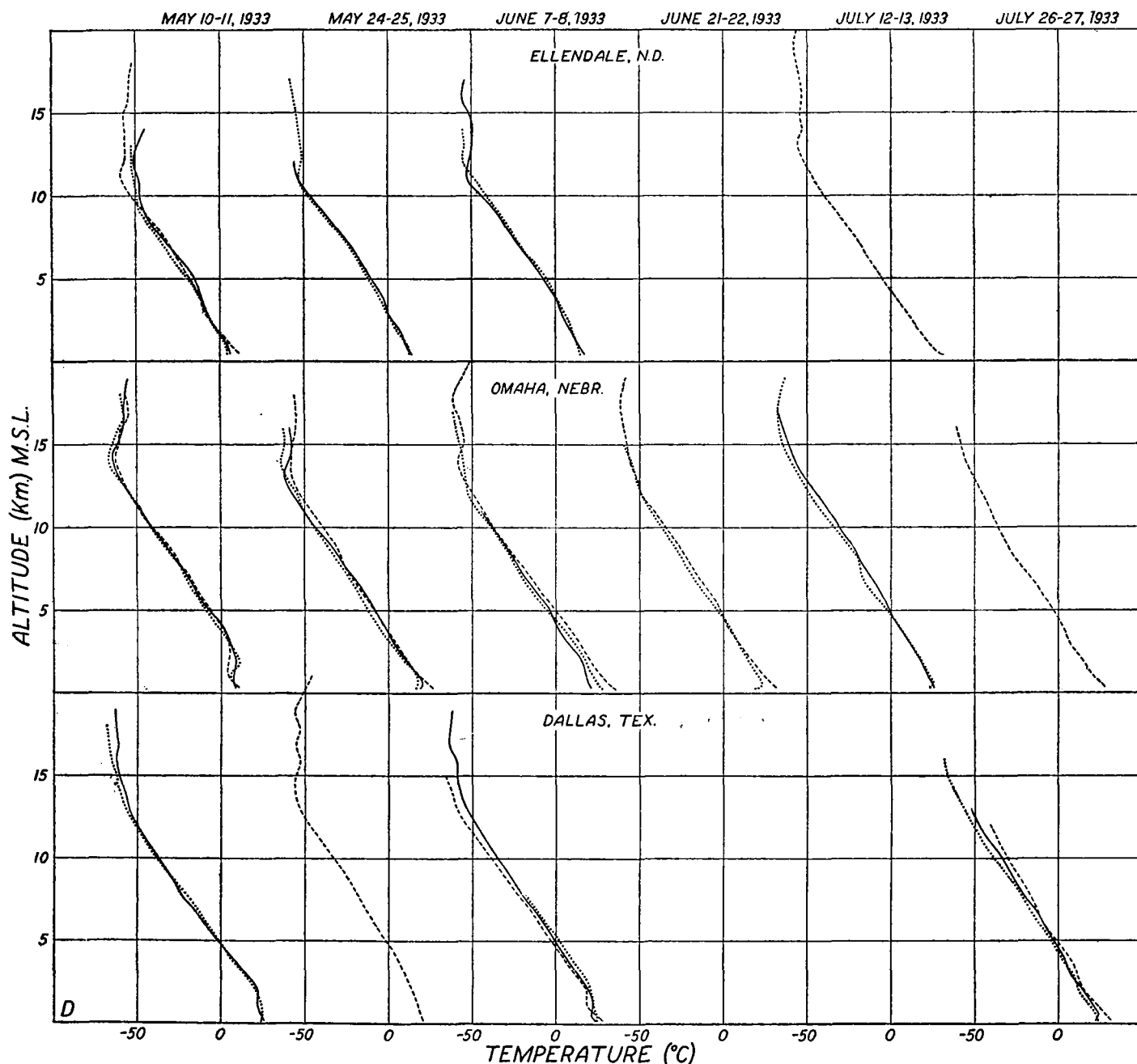


FIGURE 2.—(Continued.)

km up to about 10 km, and remained nearly constant above this height. The temperature fell between noon and the following morning at the surface and up to 5 km. Above 5 km the temperature rose at all levels up to the maximum height of 17 km. On February 8 and 9 the pressure fell between noon and the following morning at the surface and up to about 1.5 km, rose between this point and 10 km, and above 10 km it again fell slightly.

air above it upward to form a sort of hill of air which then flows away at the top causing expansion and cooling of the air below it. It will now be shown that the temperature changes observed on February 8 and 9 could not possibly have been caused by such a process. The method by which this is shown is a quantitative method which it is believed is generally applicable and aids materially in the study of such cases.

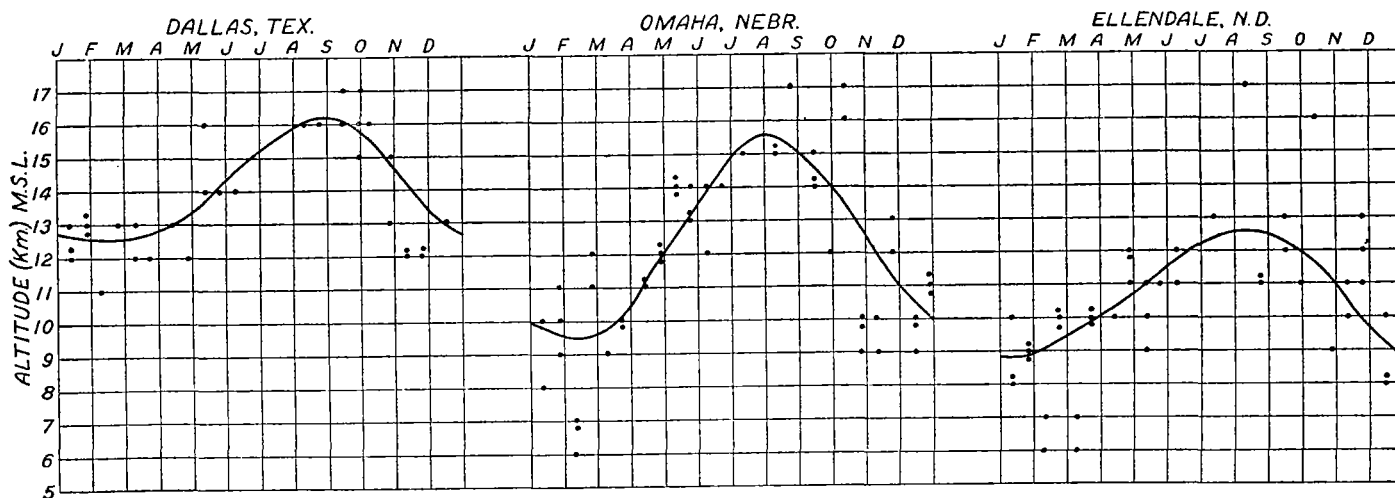


FIGURE 3.—Height of the tropopause plotted against time of year showing the annual variation.

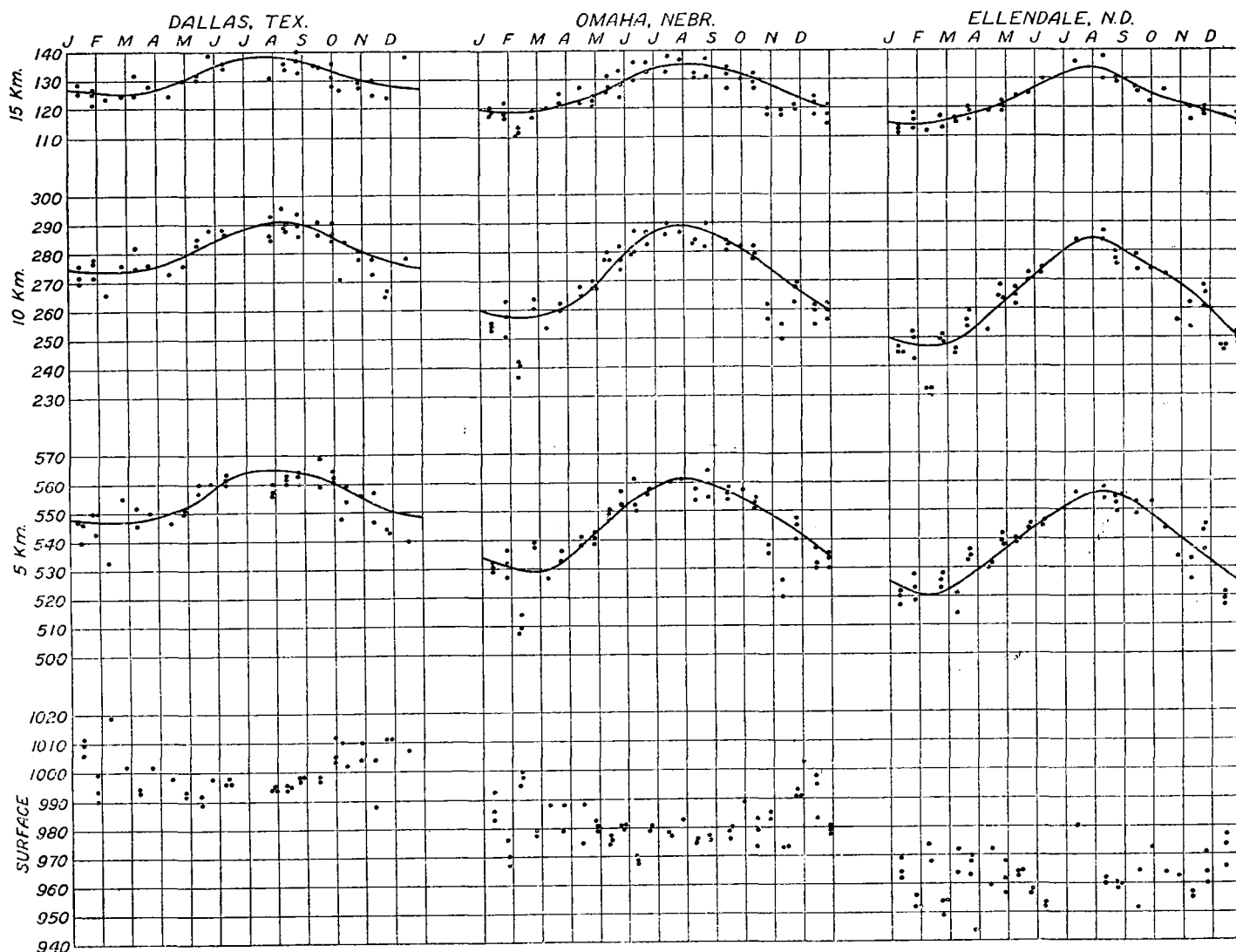


FIGURE 4.—Barometric pressure in mb plotted against time of year showing the annual variation at indicated altitudes above sea level.

By plotting the pressure recorded on any flight against altitude and integrating the curve between any two levels, it is obvious that one obtains the pressure-volume product of a column of air 1 square centimeter in cross section extending between the two levels. If the temperature of the column of air is known, then the number of mols¹ of air in the column can be calculated by means of the perfect gas equation, $PV = NRT$. If the pressure is expressed in millibars, volume in cc, and temperature in degrees Kelvin, then R obviously is 8.319×10^4 .

This calculation was carried out for the observations made at Ellendale on February 8 and 9. The units of

unit cross section between 5 and 15 km actually increased. It was thus obviously impossible for the air above 5 km to have been cooled by expansion. Similar calculations and a similar line of reasoning show that the temperature changes observed on March 8 and 9, could not possibly have been produced dynamically.

As we have seen, the air below 5 km at Ellendale was heated between noon of February 8 and the following morning and at the same time the quantity per unit volume decreased, so that the temperature rise could not have been produced by adiabatic compression. The sun was shining only a very short time during this period and likewise could not have produced the temperature rise. Hence, the temperature change must have been produced by a change of air masses. Likewise, between 5 km and 15 km such a change must have occurred. Thus the decrease of 6 mb in the surface pressure was the combined effect of a decrease in the weight per unit column of the air below 5 km of about 14 mb and an increase above 5 km of about 8 mb. The pressure at 1.5 km remained about constant but the above calculations show clearly that it would be incorrect to assume that the exchange of air masses over the station occurred at

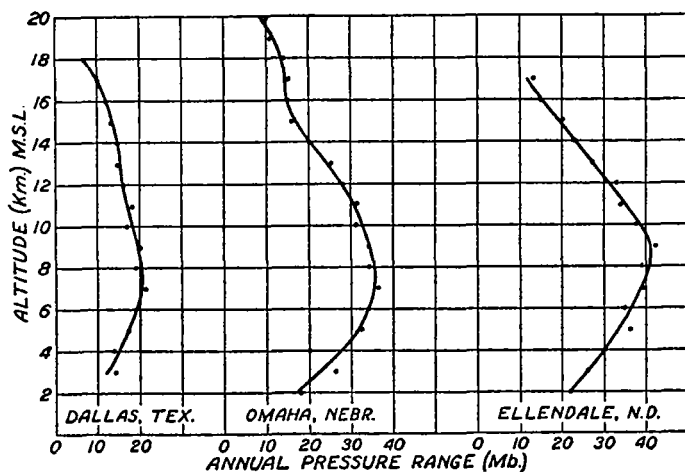


FIGURE 5.—Annual pressure range plotted against altitude.

integration used were 100-meter layers in the lower levels and 500-meter layers in the upper levels since the pressure can be considered as changing linearly within these intervals. The data obtained for these small intervals were then summed up for the intervals surface to 1 km, and for each kilometer thereafter up to 15 km. The results are shown in table 1.

TABLE 1.—Moles¹ of air between levels indicated

Intervals in km, m.s.l.	Feb. 8, 1:28 p.m.	Feb. 9, 7:32 a.m.	Change
8-1	2.671	2.546	-0.125
1-2	4.375	4.174	-.201
2-3	3.760	3.640	-.120
3-4	3.243	3.190	-.053
4-5	2.840	2.836	-.004
5-6	2.494	2.521	+.027
6-7	2.170	2.209	+.039
7-8	1.855	1.896	+.041
8-9	1.578	1.630	+.052
9-10	1.344	1.380	+.036
10-11	1.149	1.173	+.024
11-12	.987	1.006	+.019
12-13	.861	.861	+.010
13-14	.724	.732	+.008
14-15	.623	.630	+.007
8-15	30.664	30.424	-.240

¹ For definition see footnote below

It will be seen that between noon of February 8, and the following morning, the quantity of gas per unit volume decreased at all levels up to about 5 km. This change is consistent with the direction of the temperature and pressure changes but simple calculation shows that the change in amount of air per column of unit cross section from 5 km down to the surface would produce a decrease in surface pressure of about 14 mb whereas the actual decrease was only 6 mb. The number of mols of air per column of

¹ One mol of a pure substance (element or single compound) is that mass of it in grams which is numerically equal to its molecular weight. One mol of any gas, pure or homogeneous mixture, such as air, occupies approximately 22.4 liters under standard conditions of temperature and pressure.

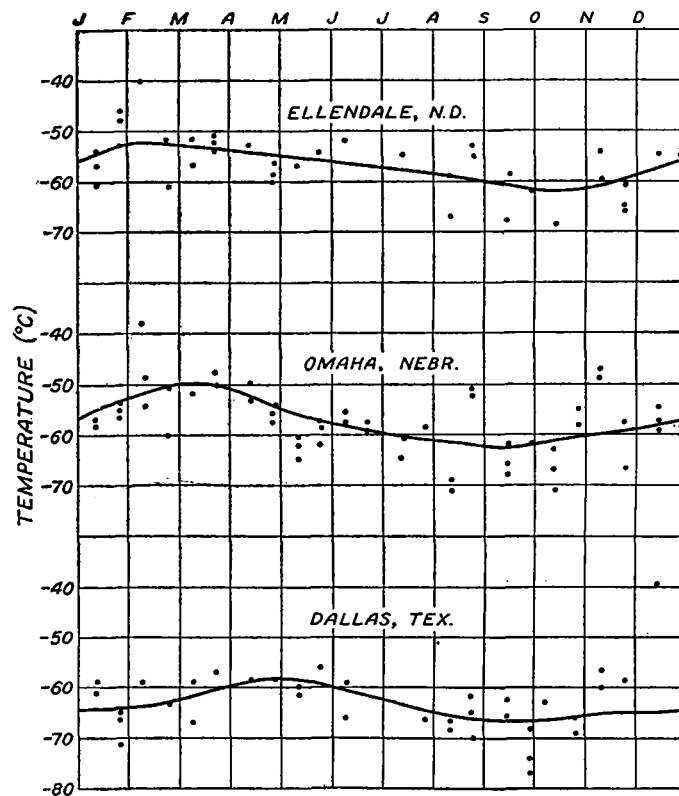


FIGURE 6.—Annual temperature variation at 15 km, m.s.l.

altitudes only up to 1.5 km. In other words, it is quite evident that the changes up to several kilometers were important in determining the total effect which was observed at the surface. It is believed that many of the so-called subsidence temperature changes would be found to be due to the importation of air having a different temperature, if they were analyzed from a rational standpoint, taking into account the observed temperature and pressure changes up to high altitudes.

It is obvious that a high pressure area, in winter at least, need not be considered as a "hill of air." The simple replacement of the first kilometer or so of relatively warm air by cold air is sufficient to produce the high pressures ordinarily observed.

The cases just given particular attention were observations in *HIGHS* coming from the northwest. Pressure areas originating in other places, especially in the southwest, probably have different properties. Unfortunately, no observations were made in pronounced *LOWS*. However, during the international month of January 1934, sounding-balloon observations were made approximately every three hours during the passage of the southern sector of a well-defined low. These data will be studied in detail and the results published as soon as possible.

THE EFFECT OF TEMPERATURE ON THE PRESSURE ELEMENTS OF THE FRIEZ AEROMETEOROGRAPH

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The classical work on the effect of temperature on pressure elements appears to have been that of Hergesell and Kleinschmidt (*Beit. z. Physik der freien Atmos.*, I Bd., 108-119 and 208-210 (1904-05)). Since that time little has been added of theoretical interest, the equation in general usage for computing the effect of temperature on Aneroid and Bourdon elements still having the form

$$\delta p = -\Delta t (A + \alpha p) \quad (1)$$

where δp is the error in the recorded pressure, Δt is the temperature of the pressure element at the time the record was made minus its temperature during the calibration, A and α are constants, and p is the recorded pressure.

The value of α depends upon the metal of which the element is constructed, and accordingly should be constant for elements of a uniform and standard make. The value of A depends, for any particular make of element, upon the quantity of air left inside the chamber. Consequently, A can vary considerably for different elements and can even change with time for a given element. The values of these two constants can be found simultaneously for any element from pressure tests made at two different temperatures by plotting $\delta p / -\Delta t$ against p . The slope of the line drawn through these points obviously gives the value of α and its intercept on the $\delta p / -\Delta t$ axis gives the value of A . Theoretically, at least, A can be determined for any particular element from tests made by subjecting the element to temperature extremes at constant pressure, once the value of α has been determined for that particular make of element.

The latter are the type of tests which are made by the Weather Bureau to determine the effect of temperature and the method of correction has been equivalent to assuming that α was zero, it being believed that α is very small. It has been frequently observed, however, in these tests that the position of the pressure pen changed with a change in temperature (pressure remaining constant) until some temperature in the region of 0° C. to -10° C. was reached, after which a further decrease of temperature caused little or no further variation in the position of the pressure pen. This performance was in direct disagreement with the assumption made in using equation 1 that the effect of temperature is linear with respect to temperature. The tests described below were made for the purpose of verifying or disproving the applicability of this equation to the Friez aerometeorograph, and if the equation were found applicable to determine the value of α for several instruments.

Two series of pressure tests were made in which five aerometeorographs were tested sufficiently to permit

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several values of α to be obtained for each instrument. In the first series, tests were made at approximately 28°, -4°, -15°, and -35°C. The second series was made at approximately 28.5°, 18.5°, 14.5°, 9°, 4.6°, -0.3°, -8.5°, and -22.4° C. During the second series of tests care was taken to keep the relative humidity 100 percent inside the bell-jars. For each test the pressure pen deflection was plotted against observed pressure in the bell-jar (measured with a mercurial barometer) and a straight line drawn through the points. This line is called the test curve.

The first series of tests thus furnished four test curves for each instrument. The slopes of these curves were plotted against temperature. For each instrument the three slopes at the low temperatures fell near a straight line which did not pass near the point, showing the slope of the test curve at room temperature. These results were thus in agreement with those indicated by the tests described above at constant pressure but were so unsound theoretically that it seemed apparent that some extraneous factor was producing spurious results. The only apparent difference between the test at room temperature and the others, besides temperature, was the relative humidity in the jar, which was low during the former test but was 100 percent during the latter tests because the temperature inside the jar was lowered below the dew-point. It was therefore decided to make the second series of tests keeping the humidity constant at 100 percent during the tests at relatively high temperatures.

The slopes of the test curves obtained in the second series of tests were plotted along with those of the first series and both sets of points clustered about a common straight line, which, as before, was well removed from the point representing the slope at low humidity.

The results indicated that the effect of humidity on the paper record sheet can be of the same order of magnitude as the effect of temperature on the pressure element.

The mean value of α weighted on the basis of the scatter of the points in the graph just described was found to be -0.00013, the individual values ranging between -0.00004 and -0.00018.

Since the compensation pressure (i.e., that pressure at which the temperature effect is zero) of most of these elements is near normal surface pressure, it is quite obvious that the errors in the pressures recorded at the higher levels in airplane flights, on the average, are of the order of 4 mb., if it is assumed that α is zero. However, if the compensation pressure were about 600 mb., it can easily be shown that the errors in the recorded pressures would very seldom be larger than 1 mb. at any pressure if no correction were applied for temperature effect. In view of this fact it was recommended that further investi-